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IDENTIFICATION OF LOW CYCLE FATIGUE PARAMETERS OF HIGH STRENGTH LOW-ALLOY (HSLA) STEEL AT ROOM TEMPERATURE

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Low cycle fatigue test was performed in ambient atmosphere at room temperature. Cycle loading of material, in case of High strength low-alloy steel, entails modifications of its properties and in this paper is therefore shown behavior of fatigue life using low cycle fatigue parameters. More precisely, crack initiation life of tested specimens was computed using theory of Coffin-Manson relation during the fatigue loading. The geometry of the stabilized hysteresis loop of welded joint HSLA steel, marked as Nionikral 70, is also analyzed. This stabilized hysteresis loop is very important for determination of materials properties.

Key words: HSLA steel, mechanical properties, low cycle fatigue, fatigue life, material parameters

INTRODUCTION

When it comes to the designing of cyclic loaded engineering structures and components, the prediction of their integrity and life is of great importance. The fatigue life estimation is generally carried out by using fatigue damage parameters of stress, strain and energy-related terms. To evaluate fatigue deformation behavior of HSLA steel, total strain-controlled and stress-controlled low cycle fatigue test were performed using round specimens. Testing procedure of the material resistance to LCF consists of two relations: Coffin-Manson relation, it represents strain-life curve, and Ramberg-Osgood stress-strain relation, which represents cyclic stress-strain curve [1]. This paper is based on Coffin-Manson relation for determining parameters during fatigue loading at room temperature.

EXPERIMENTAL PROCEDURE

The LCF test was performed on a universal servo-hydraulic MTS test machine, with 500 kN capacity, interfaced to a computer for machine control and data acquisition. For this experiment of low cycle fatigue 10 specimens were investigated.

This research was conducted using welded joint of Nionikral 70 (NN-70), a high strength low-alloyed steel [2]. Main chemical composition of NN-70 are shown in Table 1. EVB 75, alloyed basic electrode, in diameters of 2,5 and 3,25 mm, was chosen fot the plates welding. The choice was made according to the base material properties and the chosen welding procedure, in this test manual metal arc welding. In Table 2 chemical composition of electrode EVB 75 are given.

Table 1 **Chemical composition of Nionikral 70 / % wt**

C	Si	Mn	P	S	Cr
0,106	0,209	0,220	0,005	0,017	1,258

Table 2 **Chemical composition of filler material / % wt**

C	Si	Mn	Ni	Mo	Cr
0,06	0,50	1,50	2,10	0,40	0,40

Loading applied during the tests was oscillating sinusoidal with the strain ratio $R_{\varepsilon}=\varepsilon_{min}/\varepsilon_{max} = -1$. In general, strain ratio is defined such as ratio between the minimum and the maximum ratio. The tests were conducted at five levels of total strain amplitude $\Delta\varepsilon/2$: 0,40, 0,50, 0,60, 0,70 and 0,80 % [3], see Table 3. The frequency of load changes f during the test amounted to 0,233 Hz for period T of 4,30 s.

Table 3 **Data of strain amplitude and strain for welded joint NN-70**

Specimen	Total strain amplitude $\Delta\varepsilon/2$ / %	Total strain $\Delta\varepsilon$ / %
1	0,40	0,80
2	0,40	0,80
3	0,50	1,00
4	0,50	1,00
5	0,60	1,20
6	0,60	1,20
7	0,70	1,40
8	0,70	1,40
9	0,80	1,60
10	0,80	1,60

During fatigue tests the hysteresis loops were measured by using the signals acquired from the load cell

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Figure 1 MTS extensometer during fatigue loading

and the extensometer (gauge length is 25 mm) attached to the each specimen (diameter 7 mm), in Figure 1. In the case of welded joint of HSLA steel NN-70, fatigue tests were interrupted in correspondence to the failure of the specimen.

The low cycle fatigue behavior has been analyzed in terms of cyclic stress response and cyclic strain life relation. Due to the observed cyclic loading of tested material, the strain life curve, which contains the Coffin-Manson relation, was evaluated according to ASTM E 606 [4]. Values in Coffin-Manson relation are recorded at 50 % of the total fatigue life.

After getting informations about controlled strain in order to define cycle of stabilized hysteresis loop [3,5], curves of extreme stress values have been constructed with a certain number of cycles to failure (N_f), marked as cyclic-stress response curve. With cyclic stress response curves at different strain amplitudes, stabilized hysteresis loops were defined, in order to form parameters during fatigue loading of welded joint.

RESULTS AND DISCUSSION

A fundamental step in the strain-life fatigue analysis of cyclic property data is the decomposition of the total cyclic strain amplitude ($\Delta\varepsilon/2$) into its components, plastic strain amplitude ($\Delta\varepsilon_p/2$) and elastic strain amplitude ($\Delta\varepsilon_e/2$) according to the equation:

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_p}{2} + \frac{\Delta\varepsilon_e}{2} \tag{1}$$

The formula (1) is decomposed more precisely (2) and is often referred to as the Coffin-Manson relationship:

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_p}{2} + \frac{\Delta\varepsilon_e}{2} = \varepsilon_f^{'}\, N_f^c + \frac{\sigma_f^{'}}{E}\, N_f^b \tag{2}$$

where ($\Delta\varepsilon/2$), ($\Delta\varepsilon p/2$) and ($\Delta\varepsilon e/2$) are total, plastic and elastic strain amplitudes, respectively [3].

In this equation, the four additional fatigue parameters needed are: $\varepsilon^{'}_f$ - fatigue ductility coefficient, c - fatigue ductility exponent, $\sigma^{'}_f$ - fatigue strength coefficient and b - fatigue strength exponent.

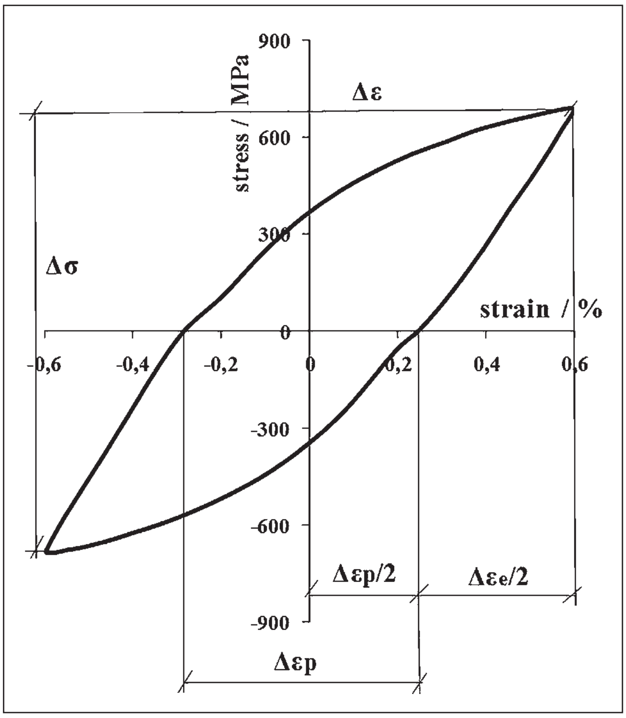

Figure 2 Example of stabilized hysteresis loop

The strain-bassed approach may be regarded as a comprehensive approach describing both elastic and plastic behavior of a material. This approach is now commonly used in fatigue design, particularly in the ground vehicle industry.

There are many ways to determine number of cycles to failure (N_f). In this test, N_f is defined as the number of cycles corresponding to a decrease of 25 % in the stress value extrapolated over the tensile stress-number of cycles curve when the stress falls sharply, accordind standard ISO 12106 [6]. Cycle of stabilized hysteresis loop (N_s) was considered at half of number of cycles to failure (0,5N_f). Characteristics of the quantities of the stabilized hysteresis loop were used for developing the basic fatigue characteristics of this steel [3]. In Figure 2, is plotted one stabilized hysteresis loop for 0,60 % of total strain amplitude for specimen with values of N_s=290 [7].

Obtained data were also used to define the slopes of regression lines applied for the description of dependence between stress amplitude and strain amplitude. From hysteresis loop, were obtained results of maximum and minimum stress and stress amplitude, see Table 4, where values for specimen of 0,60 % of total strain amplitude are given (Figure 2).

Table 4 **Stabilized hysteresis values for 0,60 % of total strain amplitude**

number of cycles to failure, N_f / -	580
number of cycle of stabilized hysteresis loop, N_s / -	290
total strain amplitude, $\Delta\varepsilon/2$ / %	0,60
plastic strain amplitude, $\Delta\varepsilon_p/2$ / %	0,2474
elastic strain amplitude, $\Delta\varepsilon_e/2$ / %	0,3526
plastic strain range, $\Delta\varepsilon_p$ / %	0,49
maximum stress value, σ_{max} / MPa	686,82
minimum stress value, σ_{min} / MPa	685,35
stress amplitude, $\Delta\sigma/2$ / MPa	686,08

The elastic and plastic components of equation (2) were linearized in log-log system, relations (3) and (4), to determine ductility and strength properties.

$$\log\frac{\Delta\varepsilon_p}{2} = c\,\log\,N_f + \log\,\varepsilon_f' \tag{3}$$

$$\log\frac{\Delta\varepsilon_e}{2} = b\,\log\,N_f + \log\,\frac{\sigma_f'}{E} \tag{4}$$

After getting parameters of hysteresis loop, number of cycle to failure and plastic strain amplitude formed linearized plastic component of strain-life curve. Also, such as plastic component, elastic component was obtained using number of cycle to failure and elastic strain amplitude. Average modulus of elasticity is determined in first 1/4 of cycle, over a 10 specimens (203,5 GPa). In Table 5 are given material parameters of NN-70 steel during fatigue loading.

Table 5 **Fatigue parameters for welded joint of HSLA steel (NN-70)**

σ'_f / MPa	b / -	ε_f' / -	c / -
994,34	-0,061	0,2312	-0,684

where are: σ'_f - fatigue strength coefficient, b - fatigue strength exponent, ε_f' - fatigue ductility coefficient and c - fatigue ductility exponent.

With fatigue parameters of welded joint of HSLA steel in Table 5, was formed final equation of strain life curve [8], known as Coffin-Manson relationship (2) for welded joint of HSLA steel, marked as Nionikral 70:

$$\frac{\Delta\varepsilon}{2} = 0,2312\;N_f^{-0,684} + 0,0049\;N_f^{-0,061} \tag{5}$$

Using this relation (5), in the end, fatigue life curve is plotted, see Figure 3, where elastic, plastic and total components are represented [9]. In general, the fatigue analysis is based on strain-life method, where Coffin-Manson relationship depends of the number of cycles to failure.

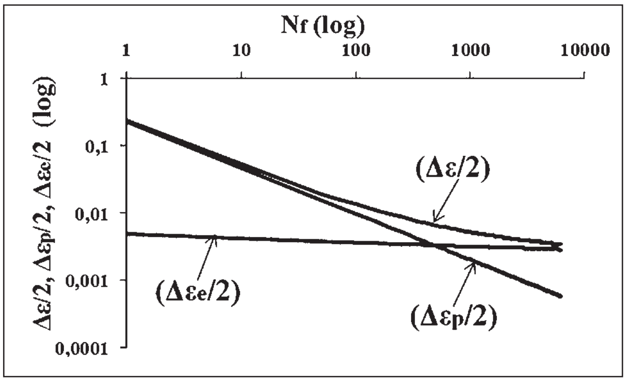

Figure 3 Fatigue life curve of welded joint NN-70

CONCLUSIONS

In this paper, the importance of the strain-life curve, using Coffin-Manson relationship, was discussed showing the low cycle fatigue parameters for welded joint of high strength low-alloy steel at room temperature.

This parameters are one of the important material properties and indispensable to perform the fatigue design. Analysis applied to fatigue crack initiation assume that a unique relation exists which describes the strain path of cyclic loading. Thus, fatigue life is characterized by Coffin-Manson relationship where the total strain range can be divided into elastic and plastic range. It can be concluded that Coffin-Manson power equation can fit the test data rather well.

The results obtained in this experiment of low cycle fatigue show the real material behavior for future design welded joints of HSLA steel on fatigue.

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Note: Responsible person for english translation: prof. Anđa Zorica, professional translator from Belgrade, Serbia